Location-Aware Forwarding and Caching in CCN-Based Mobile Ad Hoc Networks

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SUMMARY Content centric network (CCN) is conceived as a good candidate for a futuristic Internet paradigm due to its simple and robust communication mechanism. By directly applying the CCN paradigm in wireless multihop mobile ad hoc networks, we experience various kind of issues such as packet flooding, data redundancy, packet collisions, and retransmissions etc., due to the broadcast nature of the wireless channel. To cope with the problems, in this study, we propose a novel location-aware forwarding and caching scheme for CCN-based mobile ad hoc networks. Extensive simulations are performed by using simulator, named ndnSIM. Experiment results show that proposed scheme does better as compared to other schemes in terms of content retrieval time and the number of Interest retransmissions triggered in the network.

key words: ad hoc networks, location, named data networking, caching, content centric network, energy

1. Introduction

Traditional TCP/IP based Internet architecture was proposed over 40 years ago and it is hard to enhance the services and communication functionalities which is also known as ossification of Internet [1]. Mobile ad hoc networks (MANETs) are formalized by randomly deploying resource constrained mobile nodes, despite any centralized infrastructure. By using TCP/IP based protocols, we need to establish and sustain an end-to-end path between source and destination node in order to communicate. It is hard to obtain this functionality in wireless ad hoc networks due to the high dynamic nature of mobile nodes. Therefore, content centric networks (CCN) [2] become a good candidate for futuristic Internet paradigm. Due to its robust and simple communication methodology, it has rapidly gained huge popularity and consensus in research community. CCN supplies the built-in characteristics such as multicast data delivery, data authenticity, in-network caching etc. Previously, most studies done in this domain were related to wired networks. However, it also earn attraction in wireless ad hoc networks [3] and cognitive radio ad hoc networks (CRAHNs) [4]. In [5], the authors propose a proactive-based packet broadcasting scheme for wireless CCN networks. In which, EFS and EFS-ACK packets are periodically used for forwarding purpose. Two metrics (i.e. hop distance and link quality) are utilized for the selection of forwarder node. Authors of previous work [6] presented an efficient content distribution scheme, called AIRDrop that conveys the data packet in a unicast manner. This scheme utilizes the extra data structures (i.e. buffers and tables) which further cause an overhead in the network. Marica et al., in [7], introduces two kind of forwarding strategies, named blind forwarding (BF) and provider-aware forwarding (PAF) for named data wireless ad hoc networks. BF represents a kind of controlled flooding scheme that mitigates the packet flooding over the network. On the other hand, PAF scheme also consider the location of the provider node by using the distance approach based on hop count.

None of the above schemes take into account the remaining energy of the node which is an important factor in resource constrained networks (i.e. MANETs). Moreover, in literature, mostly provider-aware schemes are grounded on hop count based approach that is not appropriate in high mobility case. On the other hand, mostly schemes applied the leave copy everywhere caching policy (i.e. all nodes can cache data packets) which cause the data redundancy problem in the network.

Therefore, in this study, we propose a novel location-aware forwarding and caching scheme for CCN-based MANETs. It is assumed that all the nodes know about their current locations at any time by using the global positioning system (GPS). Proposed scheme takes into account the location of the consumer and provider nodes while sending Interest and Data packets. Both Interest and Data packets follow multipath forwarding technique that has two main advantages: Firstly, high reliability is achieved in transmitting Interest and Data packets. Secondly, on return Data packet follows multiple paths. Consequently, content widely spreads over the network which reduces the content download latency for future requests. In parallel, proposed scheme also considers the distance-based caching scheme that mitigates the Data redundancy as well as collision probability. It gives priority to cache data near to the consumer node instead of provider node. Proposed scheme sustains the rule of the conventional CCN and does not utilize any extra tables, buffers or control packets etc. The key contribution of this study is as follows:

- An on-demand and reactive forwarding scheme is pro-
posed that considers the nodes current locations in its forwarding mechanism. To the best of our knowledge, this is the first work that takes into account the geolocation-based forwarding and caching in CCN-based mobile ad hoc networks.

- Content discovery and delivery mechanism utilize the multipath forwarding methodology that enhances the reliability of both Interest and Data packets as well as reduce the content download time for future requests
- Proposed scheme also considers the remaining energy of the nodes in its forwarding mechanism and enhances the node as well as network performance
- Distance-based caching concept is introduced that mitigates the data redundancy in the network

The rest of this paper is devised as follows. In Sect. 2, the explanation of the proposed scheme is presented. Section 3 describes the experiment results and analysis. Finally, conclusions are provided in Sect. 4.

2. Proposed Scheme

An on-demand location-aware forwarding and caching scheme is proposed in this paper. When a consumer node needs a Data packet, it broadcasts an Interest packet with its current position (i.e. x and y coordinates). On the reception of the packet, the relay node calculates the distance by using Euclidean distance formula (i.e. $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$) and checks if it is closer to the provider node. If yes, it forwards the request packet. Otherwise, it discards the packet. In addition to distance, it also checks the remaining energy ($E_{rem}$) of the node during forwarding process. If the node has lower energy than energy threshold ($E_{thres}$), it discards the transmission of the request packets and pays more focus on forwarding Data packet. If $E_{rem} < E_{thres}$, then the node is in critical state. A relay node is an eligible Interest forwarder (EIF) if

$$Dis_{rp} <= Dis_{cp} and E_{rem} > E_{thres} \hspace{1cm}(1)$$

where, $Dis_{cp}$ and $Dis_{rp}$ denote the distance between consumer node to provider node and relay node to provider node, respectively. On the reception of the Interest packet, the provider node sends the Data packet back towards consumer node. The relay node who receives the Data packet also calculates its distance to consumer node. If it is closer to the consumer node, it forwards the Data packet. Otherwise, it discards the packet. A relay node is an eligible Data forwarder (EDF) and caching Data packet if

$$Dis_{rc} <= Dis_{pc} \hspace{1cm}(2)$$

where $Dis_{rc}$ and $Dis_{pc}$ denote the distance between the relay node to consumer node and provider node to consumer node, respectively. In the proposed scheme, each node performs distance-based caching mechanism in order to avoid the Data redundancy in the network and caches Data packets only on that nodes which are near to the consumer node.

Proposed scheme utilizes two types of packets, named Interest packet (INT-Msg) and Data packet (DATA-Msg) during its communication process. Both packets are based on conventional CCN Interest and Data packets, but they contain three additional fields, named consumer position, relay position, and provider position which contain the (x, y) coordinates of the respective nodes. Consumer and provider node’s positions are updated on each INT-Msg and DATA-Msg packet transmission. Every node has two types of data structure, called Content store (CoS) and Pending Interest Information Table (PIIT). CoS is used to store the DATA-Msg locally for future usage. On the other hand, PIIT is for the management of the INT-Msg packets.

To mitigate the packet collisions and duplication, each participating node randomly defers and sense the channel for some duration (i.e. $T_{INT-Msg}$, $T_{DATA-Msg}$). If same INT-Msg or DATA-Msg packet is received during this time, then the relay node terminates the current transmission.

Algorithm 1 describes the overall INT-Msg processing at a relay node. Firstly, a relay node checks that presently received packet is not expired or duplicated. In next stage, it checks its CoS for the required DATA-Msg (line 3). If

\begin{algorithm}
1: If (INT-Msg is Duplicate or Expired) then
2: Discard the INT-Msg packet
3: else if (INT-Msg found in CoS) then
4: Calculate and check node distance
5: If ($Dis_{cp} < Dis_{rp}$) then
6: Update the position information in DATA-Msg
7: Listen and wait for $T_{DATA-Msg}$
8: If (the same DATA-Msg is detected) then
9: Discard the DATA-Msg transmission
10: else
11: Send DATA-Msg back to the consumer node
12: Discard PIIT entry
13: end if
14: else
15: Discard the DATA-Msg transmission
16: end if
17: else if (INT-Msg found in PIIT) then
18: Discard the INT-Msg packet
19: else
20: Check node remaining energy
21: If ($E_{rem} < E_{thres}$) then
22: Insert a new entry in PIIT table
23: Discard INT-Msg packet
24: else
25: Calculate and check node distance
26: If ($Dis_{cp} < Dis_{pc}$) then
27: Insert a new entry in PIIT table
28: Update the position information in INT-Msg
29: Listen and wait for $T_{INT-Msg}$
30: If (the same INT-Msg or DATA-Msg is received) then
31: Discard the INT-Msg and cancel PIIT entry
32: else
33: Forward INT-Msg packet
34: end if
35: else
36: Discard the INT-Msg transmission
37: end if
38: end if
39: end if
\end{algorithm}
it is available, then relay node calculates and compares the distance towards consumer node. If it has less distance as compared to previous node (line 5), the relay node updates its position information in DATA-Msg and forwards it to the next node. Moreover, before forwarding the DATA-Msg, the node has to wait for $T_{DATA-Msg}$ time (line 7). If it receives the same DATA-Msg within this time, it discards its current transmission. Otherwise, it forwards the DATA-Msg packet towards the consumer node. If the INT-Msg is not found in CoS, the relay node checks its PIIT table (line 17). If there is an entry, it means some nodes already requested the DATA-Msg packet. As a result, it discards the current INT-Msg transmission.

On the other hand, it checks the node’s remaining energy ($E_{rem}$) (line 20). If it is less than $E_{thres}$ (i.e. critical state), it adds the new entry in PIIT and discards the transmission. Otherwise, it calculates and checks the distance heading towards the provider node (line 25). If the distance is less as compared to previous node, it makes a new entry in PIIT table. Furthermore, the relay node updates its position information in INT-Msg and wait for $T_{INT-Msg}$ time before transmission (line 28). If there is no any same transmission is detected, it forwards the INT-Msg towards other nodes (line 33).

Algorithm 2 elaborates the DATA-Msg processing at the relay node. DATA-Msg follows the same multiple paths of PIIT entries towards consumer node. However, every relay node also considers its distance from the consumer node. When a DATA-Msg is received by a relay node, it checks its PIIT table for any corresponding entry for this DATA-Msg. If there is no any entry, then the relay node discards the packet (line 2). Otherwise, it calculates and compares distance towards consumer node (line 4). If it is near to the consumer as compared to a previous node, then the relay node saves the DATA-Msg packet in its CoS (line 6). Moreover, it updates its position information in DATA-Msg and forwards it after waiting for $T_{DATA-Msg}$ time (line 10). On the other hand, it discards the current transmission.

3. Simulation and Results

3.1 Experimental Environment

The proposed scheme is evaluated by using the officially CCN-based simulator, named ndnSIM [8]. By utilizing the Random Walk mobility model, nodes can freely travel anywhere in 900 x 900 area. Each node has initial energy equal to 50 J and equipped with IEEE802.11g technology-based radio interface. Presently, we take into account the one consumer/provider pair in our simulations. We consider one content that consist of 1000 packets and initially stored at the provider node. Least recently used (LRU) policy is used as a cache replacement policy for CoS. After ten time simulation runs the average values are presented in the given plots. The value of $E_{thres}$ is set to 13% after performing extensive simulations. The summary of the simulation parameters is presented in Table 1.

3.2 Experimental Results

The performances of the proposed scheme is compared with recently proposed schemes in [7] (i.e. blind forwarding (BF) and provider-aware forwarding (PAF)). In Fig. 1 (a), the average content retrieval time (i.e. time consumed by consumer node) is described as a function of the number of nodes. As the number of nodes increases, the traffic in the network also increases. Proposed scheme performs better as compared to the other schemes (i.e. BF and PAF). The reason is that, it considers the information of node’s locations in forwarding mechanism. Instead of flooding packets all over the network, proposed scheme considers the consumer and provider node’s locations before forwarding any

<table>
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<td><strong>Parameter</strong></td>
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<td>Propagation Loss Model</td>
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<td>Power Consumption (rx)</td>
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<tr>
<td>Power Consumption (idle)</td>
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<tr>
<td>Simulation Time</td>
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<td>CoS Size</td>
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<td>Nodes</td>
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<td>Data Rate</td>
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INT-Msg or DATA-Msg packets. In addition, it also considers the remaining energy of the participating nodes. On the other hand, other schemes do not consider these features. As the number of node increases, the chances of packet redundancy and collisions also increase. However, in the case of proposed scheme, more nodes are in critical state and do not forward INT-Msg packets further. As a result, less chance of packet collisions occurs which leads to low content retrieval time. However, in other schemes, the content retrieval time is increased exponentially with respect to the number of nodes.

In Fig. 1 (b), the average number of Interest retransmissions are presented as a function of number of nodes. Proposed scheme has less number of Interest retransmissions as compared to the other schemes. The reason is that, other schemes, especially BF, is based on flooding mechanism and do not consider the location of the provider or consumer node. However, PAF scheme implicitly considers the single path towards provider node. It is hard to sustain that path specially in the presence of dynamic environment where node can randomly move anywhere. As a result, more number of Interest retransmissions injects in the network. On the other hand, proposed scheme is based on multipath forwarding mechanism which ensures the high reliability particularly in CCN-based wireless mobile ad hoc networks.

4. Conclusions

An on-demand location-aware forwarding and caching scheme is proposed for CCN-based mobile ad hoc networks. The proposed scheme has four distinguishing features: Firstly, in proposed scheme, the nodes consider the location of both consumer and provider node in order to avoid packet flooding over the network. Secondly, it utilizes the multipath forwarding mechanism for both Interest and Data packets that enhance the reliability as well as reduce the content download latency for future requests. Thirdly, proposed scheme also considers the remaining energy of the nodes that enhance the node as well as network lifetime. Fourthly, it reduces the data redundancy by caching the content close to the consumer node as compared to the provider node. Extensive simulation results show that proposed scheme does better in terms of content retrieval time and injects fewer Interest retransmissions compared to other schemes.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2013R1A1A2005692).

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